VOL. 6. OCTOBER, 1952 No. 5

WELDING RESEARCH

PRICE FIVE SHILLINGS

Published by

BRITISH WELDING RESEARCH ASSOCIATION · 29 PARK CRESCENT · LONDON · W.1

WELDING RESEARCH

VOL. 6 NO. 5 OCTOBER, 1952

Published by

BRITISH WELDING RESEARCH ASSOCIATION

Head Office and Metallurgical Laboratory

29, PARK CRESCENT, LONDON, W.1

Telephone: Langham 7485/9

Telegrams: Weldaserch, Wesdo, London

Research Station

Abington Hall, Abington, nr. Cambridge

Telephone: Linton 375

Telegrams: Weldaserch, Cambridge

Director of Research

H. G. TAYLOR,
D.SC.(ENG.), D.I.C., M.I.E.E., F.INST.P.

Secretary

A. O'NEILL, B.SC.(ECON.), A.C.I.S.

Editor and Publications Officer

J. H. GAMESON

CONTENTS

	Page
Association Notes	87*r*
C.T.S. Weldability Test for High-Tensile Structural Steels	89*r*
Surface Cleaning of Some Aluminium Alloys Prior to Spot Welding..	93*r*

ASSOCIATION NOTES

MEMBERSHIP

Since the report in the April, 1952, issue of the Journal the following companies have joined the Association:

Members

Alkaline Batteries Ltd.
Anderson, Boyes & Co. Ltd.
Carrier Engineering Co. Ltd.
Central Standards Office for Railways (India).
Dewrance & Co. Ltd.
Ferguson Pailin Ltd.
Charles McNeil Ltd.
The Metal Box Co. Ltd.
Alan Muntz & Co. Ltd.
Newman, Hender & Co. Ltd.
Percival Aircraft Ltd.
Robey & Co. Ltd.
Thomas Smith & Sons (Rodley) Ltd.
Stothert & Pitt Ltd.
Suffolk Iron Foundry (1920) Ltd.

Associate Members

Brandt & O'Dell.
Drake & Fletcher Ltd.
Fourways (Engineers) Ltd.
Scott & Wilson.
Sir Bruce White, Wolfe Barry & Partners.

WELDING PRODUCTIVITY

The members of the specialist team on welding who visited America late in 1950 have now given many lectures throughout Great Britain on their findings, and a report on their survey of American welding practice has been published by the Anglo-American Council on Productivity.

The report is available from the Association at 3s. 6d. per copy, post free, on request to the Publications Department, 29, Park Crescent, London, W.1.

R.85

C.T.S. WELDABILITY TEST FOR HIGH-TENSILE STRUCTURAL STEELS

WELDED BY THE METAL-ARC PROCESS

The test described was originally developed under the guidance of the FM.2 Committee of the British Welding Research Association for incorporation in specifications, etc. The final report of the committee, issued to members of the Association in February 1951, *has been prepared for publication by B. J. Bradstreet, B.Sc.*

The test is based on the work reported under the title : "Correlation of Weldability Tests with Structural Joints," which was published in the February, April and June 1952 *issues of this journal.*

INTRODUCTION

Reliable metal-arc welded connections may be made in steels of almost all chemical compositions given appropriate conditions of joint restraint, parent metal thickness, initial metal temperature, weld bead section, method of deposition and constitution of electrode. The first three of these conditions cannot readily be varied in actual structures, while the latter conditions may not be sufficiently variable to ensure a sound weld. Because of such limitations, steels of certain ranges of chemical composition are classified as being of "welding quality" (e.g. B.S. 968-1941), but a demand exists for a test which will indicate the actual welding behaviour of a particular cast of steel. It is not always feasible to carry out chemical analysis of every cast in consignments of structural material, and the ordinary chemical analysis will not necessarily indicate the welding behaviour of a steel.

The test was required for testing material in the form of angle, channel, plate, etc., from which only narrow and relatively thin specimens might be obtainable, so the test assembly was designed to require the minimum amount of material. The assembly can be preheated, but the use of preheat has not been included in the present assessment of weldability.

Weldability, as understood for the purposes of this test, is essentially a measure of the resistance of a steel to the development of cracks in the welded joint, particularly in the heat-affected zone adjacent to the weld bead. It is not directly concerned with the development of fatigue cracks in a welded structure, which may be caused by stress concentration effects in metal which is initially quite ductile and free from cracks.

Laboratory tests requiring expensive apparatus have been excluded, the aim being to provide a simple test for use under workshop conditions. The procedure outlined below has been based on the metal-arc welding process, and is known as the C.T.S. (Controlled Thermal Severity) test.

DISCUSSION OF THERMAL SEVERITY

Recent investigations have shown that the major factor affecting the initiation of cracks in the heat-affected zone adjacent to a weld is the cooling rate of this zone after welding, and particularly the cooling rate in the temperature range 200-400 deg. C. At these temperatures heat loss by radiation and convection can be neglected, and the cooling rate is entirely dependent on the rate of conduction of heat away from the weld through the plate. This depends upon the number of paths avilable for heat flow, and on the thickness of the plate which provides these paths. These two factors have been taken into account in determining what has been described as the "thermal severity" of a welded joint.

The unit of thermal severity has been taken as the heat flow through one thickness of $\frac{1}{4}$ in. plate, and therefore thermal severity No. 2, which is the least severe test which can be chosen from the series of tests described, is obtained by laying a weld fillet in a position where heat can flow away from it through *two* thicknesses of $\frac{1}{4}$ in. plate. With $\frac{1}{2}$ in. plate the heat flow will be twice as great as for $\frac{1}{4}$ in. plate, and therefore a similar fillet weld laid on two thicknesses of $\frac{1}{2}$ in. plate, where heat can flow in only one direction along each plate, will represent thermal severity No. 4, and so on.

It has been found that the relationship between the rate of cooling and the total section for heat flow is approximately linear. It has also been found that for a particular size of weld, there is a limiting thermal severity beyond which any increase in plate thickness or in the number of paths along which the heat can flow, makes very little difference in the rate of cooling. For instance, when a fillet of $\frac{1}{4}$ in. leg length is used, thermal severity No. 12 approximates to an infinite heat sink, and an increase in thermal severity above this value does not cause any increase in the cooling rate of the weld zone. This severity is represented by a test where a fillet weld is laid on two plates of 1 in. thickness, and where the heat can flow away from the weld through three thicknesses of plate.

When a fillet size greater than $\frac{1}{4}$ in. leg length is used, thermal severity No. 12 no longer represents an infinite heat sink, and the larger the weld, the higher the limiting value of the thermal severity number.

It can be seen from the above explanation that the thermal severity number for test weld R in Fig. 1 is $\frac{t+b}{\frac{1}{4}}$ or $4(t+b)$, and for test weld S it is $\frac{t+2b}{\frac{1}{4}}$ or $4(t+2b)$, where t and b are the thickness in inches of the top and bottom plate respectively.

The thermal severity number of any given structural joint can be similarly calculated, and the weldability of a steel can then be assessed on a C.T.S. test having approximately the same thermal severity (i.e. the same cooling conditions) as the joint.

The thermal severity numbers of the C.T.S. test assemblies most often used are shown in Tables I (*a*) and I (*b*).

Table I (a)

Test Assembly	Test Weld	Thermal Severity No.
$\frac{1}{4}$ in. top plate on $\frac{1}{4}$ in bottom plate	R	2
	S	3
$\frac{1}{4}$ in. top plate on $\frac{1}{2}$ in bottom plate	R	4
	S	6
1 in. top plate on 1 in. bottom plate	R	8
	S	12

Table I (b)—Alternative Assemblies

Test Assembly	Test Weld	Thermal Severity No.
$\frac{1}{4}$ in. top plate on $\frac{1}{2}$ in. bottom plate	R	3
	S	5
$\frac{1}{4}$ in. top plate on 1 in. bottom plate	R	6
	S	10

Where only thin material is available in the steel under test, added thermal severity can be obtained by increasing the thickness of the bottom plate, as indicated in Table I (*b*). This bottom plate can be of mild steel.

Thermal severity numbers of various other assemblies are given in the Appendix.

GENERAL DESCRIPTION OF TEST

The test comprises a series of restrained fillet welds, using the steel and electrode under consideration.

Each C.T.S. test assembly incorporates two test welds of equal size, one of which may be considered to have a thermal severity equivalent to that of a butt weld in the material under test, and the other a thermal severity equivalent to that of a normal fillet weld in the same material. This difference in severity is due to the geometry of the assembly. An examination of the test weld is made to determine whether cracking has occurred in either the weld metal or the heat-affected zone of the parent plate.

An examination for pronounced porosity in the weld metal should also be made and reported.

The test may be used for:—

(*a*) The determination of the general weldability of a given steel.

(*b*) The determination of weldability for a specific constructional purpose.

(*c*) The selection of the most suitable electrode for welding a given steel.

PREPARATION OF TEST ASSEMBLY AND WELDING PROCEDURE

When material of suitable size and shape is available, the test plates should be prepared in accordance with details given in Fig. 1, both plates being of the material under test. If there is a shortage of test material, the bottom plate may be of mild steel, complying with B.S. 15. Where the sections being used for a specific structure are not large enough to provide a 3 in. square plate, a 3 by $1\frac{1}{2}$ in. top plate may be used with a mild steel bottom plate cut to the dimensions given in Fig. 2. Values for dimensions b, t and 0 depend on the object of the test, as described later.

If gas cutting has been used, the test edges of the top plate must be machined or ground. The lower surface of the top plate and the upper surface of the bottom plate must be flat and free from mill scale; surface grinding or machining should be used if possible. The interface must be free from oil and grease when the plates are bolted together.

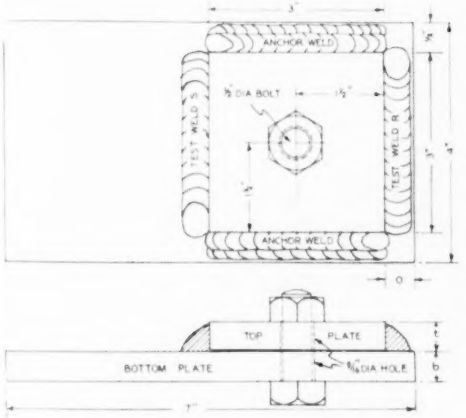

Fig. 1. C.T.S. Weldability test assembly.

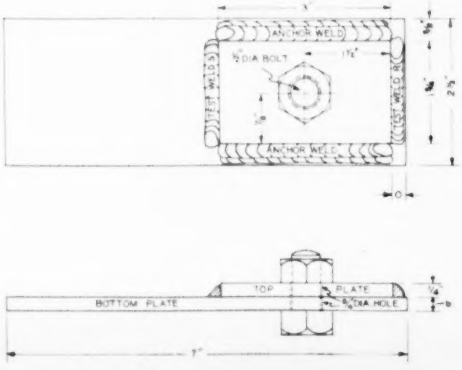

Fig. 2. Modified C.T.S. Weldability test assembly.

Anchor welds are made with the same type of electrodes as are to be used for the test welds, the welds being deposited by using the largest convenient size of electrode. Multi-run anchor welds are permitted if deposited in quick succession; visibly cracked anchor welds must be replaced. The minimum sizes of fillet for anchor welds are:

for ¼ in. top plate .. .. 0·20 in. average leg length
for ½ in. plate .. .. 0·30 „ „ „ „
for 1 in. plate and over .. 0·40 „ „ „ „

The test assembly must be allowed to cool to room temperature and any slackness in the bolt taken up before each test weld is made.

The test assembly must be held at an angle of 45 deg. to the horizontal so that the test welds are laid in the downhand position, unless any other position is specifically required to comply with the welding conditions of a particular structural joint. The test assembly must be held so that it has no metallic contact with the jig or clamping device. One way of doing this is to hold the assembly by the edges in a vise between two pieces of heat-insulating material. The earth lead should be clamped to the securing bolt. The fillet size of the test weld depends on the purpose of the particular test, as described later.

Every precaution must be taken to ensure a uniform fillet with good root penetration, and it is important that the calculated length of electrode is deposited at a uniform rate. The welder may find it helpful to mark the electrode at the estimated distance from its end in order to obtain the specified size of deposit. A half-way mark on this part of the electrode, and a chalk mark at the mid-point of the proposed weld length are also useful guides to the welder.

When two test welds are being made on the same assembly, test weld R should be laid first and the whole assembly allowed to cool to room temperature before test weld S is laid (see Fig. 1).

Electrodes used for laying the test welds should normally be stored in a warm, dry place and used immediately after removal from storage, unless a special drying technique is stipulated by the manufacturer.

METHOD OF EXAMINATION

Each test assembly should be sectioned after a minimum time of 24 hours at room temperature. The sections should then be examined for cracks, and when none are present, a final examination should be made after a further period of 48 hours, since it has been found with certain steels that cracking may be delayed for periods exceeding 24 hours after welding.

The welds should be cut out by a machine saw or milling cutter along lines XX', YY' and ZZ' as indicated in Fig. 3. The two test welds should each be cut by a hand hacksaw transversely into four pieces as shown in Fig. 3 and the three faces—L, M and N—should be polished on emery paper down to 00 grade and etched in an acid solution (5 per cent. nitric acid in water) for about one minute.

The sections should next be examined for cracks, first visually, and then by magnetic crack-detection methods. When using the magnetic method, care should be taken to avoid too powerful a magnetising field, as this tends to produce spurious markings which may be mistaken for cracks. The residual magnetism caused by the welding current may suffice, otherwise a small horseshoe magnet can be used, the test section being supported across the magnet to complete the magnetic circuit.

While the weldability index referred to here is based upon magnetic examination, cases may arise where a more rigorous inspection is desirable. In such cases, where no cracks have been found by magnetic crack detection, then the specimens should be polished for microscopical examination and etched

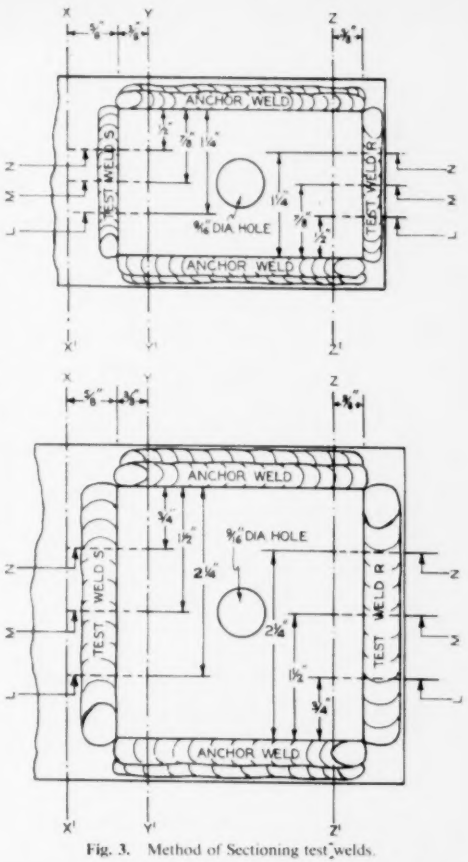

Fig. 3. Method of Sectioning test welds.

in a solution of 3 per cent. picric acid with 3 per cent. hydrochloric acid in alcohol. The specimens should then be examined at a magnification of about 200 for micro-cracks in the heat-affected zone. Any cracks found in the weld metal should also be noted.

Hardness surveys, if required, should be made as shown in Fig. 4, using a 10 kg. load on a diamond pyramid indenter. A few indentations are first made in the heat-affected zone on a line normal to the fusion line to determine the region of maximum hardness. Subsequent impressions are then made in the region of maximum hardness along a line parallel to the fusion line. The average hardness of the parent plate and of the weld metal should also be recorded.

METHODS OF EMPLOYING THE TEST

(a) General Weldability Test for a Given Steel

Where sufficient material is available, a series of test assemblies should be made using three thicknesses of plate. The three thicknesses should be ¼, ½ and 1 in., the top and bottom plates being of equal thickness in each assembly. This series will provide six test welds with six different degrees of thermal severity, as shown in Table I (*a*). Each test weld should be made under identical conditions with an 8 s.w.g. electrode of the recommended type, depositing a fillet of ¼ in. leg length. Dimension 0 in these tests (Figs. 1 and 2) should be $\frac{5}{16}$ in.

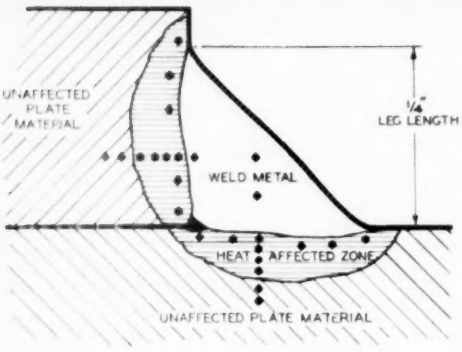

Fig. 4. Hardness survey diagram.

The weldability of the steel should then be reported in terms of (i) the particular electrode used and (ii) the weldability index indicated in Table II. The best weldability is given by index A. If the approximate weldability of the steel is known, it may not be necessary to carry out every test in the series.

The most severe test which does not produce any cracking should be repeated as a confirmatory test.

Table II

Cracking in Heat-affected Zone	Thermal Severity of Test	Weldability Index
Absent in	Number 12	A
Absent in Present in	Numbers under 12 Number 12	B
Absent in Present in	Numbers under 8 Number 8 and over	C
Absent in Present in	Numbers under 6 Number 6 and over	D
Absent in Present in	Numbers under 4 Number 4 and over	E
Absent in Present in	Numbers under 3 Numbers 3 and over	F
Present in	Numbers under 3	G

(b) Determination of Weldability for a Specific Constructional Purpose

In this instance the thickness of the plates (dimensions *t* and *b*) should be selected to simulate the conditions of thermal severity which will be present in the actual construction. For the purpose of this test, the electrodes used should be of the type which it is intended to employ in the actual construction. They will not, therefore, necessarily be limited to a size of 8 s.w.g., and dimension 0 should be made 1/16 in. greater than the leg length of the fillet which is to be deposited in test weld R. Test welds should then be made to determine whether the given steel is weldable with the given electrode.

Where the available material is limited, the bottom plate may be made from mild steel. In cases where the width of the material is limited, the assembly should be made to the dimensions shown in Fig. 2. It may not be necessary to section test weld R for examination provided that satisfactory results have been obtained from the more severe test weld S. One confirmatory repeat test should be made, as in the case of the general weldability test.

(c) Selection of an Electrode for Welding a Given Steel

Suitable tests of graded thermal severity should be determined by trial from the series given in Table I (*a*). A series of tests with 8 s.w.g. electrodes giving welds of $\frac{1}{4}$ in. leg length should be made using each type of electrode under consideration. The electrodes should be assessed in terms of the thermal severity number as determined by the most severe test which can be welded with complete freedom from cracking. One confirmatory repeat test should be made as in the case of the general weldability test.

APPENDIX

Thermal Severity Numbers for Various Test Assemblies

Top Plate Thickness *t* (in.)	Bottom Plate Thickness *b* (in.)	Thermal Severity No.	
		Test Weld R $4(t+b)$	Test Weld S $4(t+2b)$
$\frac{1}{16}$	$\frac{1}{16}$	$1\frac{1}{2}$	$2\frac{1}{2}$
$\frac{1}{8}$	$\frac{1}{8}$	2	3
$\frac{3}{16}$	$\frac{3}{16}$	$2\frac{1}{2}$	$3\frac{1}{2}$
$\frac{1}{4}$	$\frac{1}{4}$	3	$4\frac{1}{2}$
$\frac{5}{16}$	$\frac{5}{16}$	$3\frac{1}{2}$	$5\frac{1}{2}$
$\frac{3}{8}$	$\frac{3}{8}$	4	6
$\frac{1}{2}$	$\frac{1}{2}$	5	$7\frac{1}{2}$
$\frac{3}{4}$	$\frac{3}{4}$	6	9
$\frac{7}{8}$	$\frac{7}{8}$	7	$10\frac{1}{2}$
1	1	8	12

The examples given in the above table use the same thickness of material for both top and bottom plate. The following example shows how the thermal severity number can be determined when using a test assembly comprising plates of unequal thickness:

Top plate $\frac{3}{4}$ in., bottom plate $\frac{1}{8}$ in.

Thermal severity number of test weld R: $4(\frac{3}{4}+\frac{1}{8})=4$.

Thermal severity number of test weld S: $4(\frac{3}{4}+2\times\frac{1}{8})=6\frac{1}{2}$.

It will be seen that it is possible to devise a series of test assemblies of graded thermal severity without using materials of the thicknesses given in Table I. From such a series data can be obtained on the cracking in the heat-affected zone for different severities, and the weldability index of the steel can be determined by reference to Table II.

R.86

SURFACE CLEANING OF SOME ALUMINIUM ALLOYS PRIOR TO SPOT WELDING

An Account of Tests on the Pre-Resistance Welding Surface Preparation of 20, 16 and 14 S.W.G., D.T.D. 610B and D.T.D. 687 and 18 S.W.G. D.T.D 390.

An extensive programme of work on the spot welding of aluminium alloys has been carried out by the British Welding Research Association on behalf of the Ministry of Supply. The objective of the work was to improve the consistency of spot welds in aluminium alloys by suitable control of the many "variables" concerned. The research programme included investigation of surface preparation, electrode contour, load cycle and secondary current wave shape. The Association is indebted to the Ministry of Supply for permission to publish this report and it is hoped that further reports on other aspects of the work will be made available for future issues of "Welding Research." The report (LR/8A) was first issued to Members of the Association in May 1950.

By H. E. DIXON, M.Sc., A.I.M.

SYNOPSIS

The effect of sheet-to-sheet surface resistance on weld strength and consistency was to be investigated in a research programme on strength consistency of light alloy spot welds. Accordingly, information was required on the suitability of a proprietary solution A,* to determine the effect of time-of-treatment on surface resistance and scatter of individual resistance values for 20, 16 and 14 s.w.g. D.T.D. 610B and D.T.D. 687. In addition, tests were made on the effect on surface resistance of hand swabbing and flash dip in 50/50 nitric acid for the removal of surface residues which are sometimes present after treatment in the proprietary solution A. The effect of temperature and time of treatment in the final hot distilled water wash was also examined for 18 s.w.g. D.T.D. 390.

Wherever possible, the results have been expressed in the form of curves in which mean values of surface resistance are plotted against time of treatment. Selection of optimum time of treatment was made by reference to these curves and to the results of a limited variance analysis and calculated confidence limits.

It has been shown that satisfactorily low resistance and good consistency could be obtained in all material thicknesses except 20 s.w.g. D.T.D. 610B, and a recommended cleaning sequence has been established. The method of determination of surface resistance, variance analysis, and the peculiar behaviour of 20 s.w.g. D.T.D. 610B are described in Appendices I to III respectively.

It should be noted that the optimum treatment times have been derived without reference to the effect of surface resistance on spot weldability; they are concerned solely with the achievement of lowest surface resistance and highest consistency obtainable with the technique investigated. There should be no difficulty in the application of the cleaning sequence under production conditions, although it is possible that even wider ranges of treatment times may be quite satisfactory with less stringent consistency requirements.

The effect of storage time on the surface resistance of cleaned material has not been considered owing to the large fluctuations in air humidity which occurred at the time of testing due to atmospheric conditions, and which are known to affect the "storage quality" of the prepared material.

INTRODUCTION

The establishment of satisfactory cleaning techniques for the material under investigation was an important preliminary factor prior to an investigation on the spot welding characteristics of the alloys. It was not intended that the surface and cleaning investigation should involve several cleaning solutions, since previous experience with clad D.T.D. 390 had shown that very satisfactory results could be obtained with the proprietary solution A, and the materials D.T.D. 610B and D.T.D. 687 were not expected to differ greatly in their reaction. The use of this solution was also favoured because of its high stability over long periods of time and because of its use at room temperature. Detailed tests were necessary to determine whether the optimum cleaning schedule was affected by the material composition and thickness, and whether significant differences in behaviour could be expected from different sheets of the same composition and thickness.

* Proprietary Solution A. This is a solution similar in action to hydrofluosilicic acid, operated at room temperature. Nominally a 25 per cent. solution by volume of the commercially available solution is used. The strength of the solution has been checked by titration against an N/2 sodium carbonate solution as follows: 5 ml. of solution was diluted to 100 ml. with distilled water and titrated against N/2 sodium carbonate until a permanent turbidity was obtained. The titration value then obtained was 28·1 ml.

The main factors investigated were:

(i) Time of treatment in Solution A and temperature of bath.

(ii) The removal of surface residues after treatment in Solution A, by hand swabbing and 50/50 nitric acid flash dip.

(iii) Temperature and duration of hot wash in distilled water.

All material was thoroughly degreased prior to removal of oxide by chemical treatment as follows:

(*a*) Trichlorethylene vapour treatment.

(*b*) Material rubbed down with clean, dry mutton cloth to remove dirt film left after removal of protective grease.

(*c*) Treatment in Zonax Degreasing bath at 90 deg. C. for 10 minutes. (Proprietary Solution Zonax 6 ozs. per gallon.)

(*d*) Cold wash in running water to remove Zonax solution.

No investigations were undertaken on the degreasing process since all material degreased in this way presented a "no-water break" surface observable in the cold wash. The resistance of such a grease-free surface rapidly increases on exposure to the atmosphere due to the development of a very superficial oxide film, which however does not interfere with the chemical removal of the main oxide film.

After treatment in Solution A, with or without removal of residues, final washing of treated material was carried out in running water for two minutes followed by a hot distilled water (45 deg. C.) rinse for not longer than one minute.

Resistance measurements were made as soon as possible after cleaning, generally within half-an-hour and rarely after one hour.

PROCEDURE

Strips of material 6 by $\frac{1}{2}$ in. were used for cleaning tests, and these were taken from randomly selected sheets and could be assumed to comprise a representative sample for each gauge of alloy.† All strips were numbered for identification with the appropriate sheet. Specimens for a given treatment were selected randomly so that any difference between sheets or strips of the same alloy and gauge would not affect the results.

Preliminary tests were taken on 18 s.w.g. D.T.D. 390 to determine the general suitability of the Solution A bath, and the effect of temperature and treatment time in the hot distilled water wash.

Extensive tests were then carried out on specimens from 20, 16 and 14 s.w.g. D.T.D. 687 and 610B in which the variables under examination were Solution A treatment time and effect of flash dip in 50/50 nitric acid.

It was found impossible to carry out a satisfactory programme in which all the material for test purposes (i.e. all gauges of D.T.D. 610B and D.T.D. 687) was passed through the bath at the same time, owing to the large amount of material and tests required. In the ideal method tests on a given gauge of material would be randomly distributed throughout the period of time required for complete testing under all conditions, so that any process variations in bath or cleaning sequence would affect equally all the tests under given conditions. Similarly, tests on other gauges and materials would be randomly distributed and average results would show the *real* effect of the variable under test, with minimum disturbance from factors normally outside experimental control.

† In the case of 20 s.w.g. D.T.D. 687, samples were taken from three out of four sheets available, but unfortunately subsequent tests showed that this remaining sheet (designated sheet 75) reacted differently in the Solution A bath. The values obtained from this sheet are compared graphically with the values from the other sheets in Fig. 9.

The control required in supervising such an extensive test was so great that it was decided to test each gauge thickness separately. Three groups of tests were actually undertaken, corresponding to 20, 16 and 14 s.w.g. sheet, each group containing *both alloys*.

Two pairs of specimens were used for each condition under test and three determinations of sheet-to-sheet resistance made on each pair. The number of specimens used was doubled towards the point of lowest resistance on the time-of-treatment resistance curve. When more than one factor was being investigated, i.e. Solution A treatment time and flash dip in 50/50 nitric acid, all material was passed through the bath at the same time, one-half being given one treatment and the remainder the other treatment. Tests were made at one minute intervals about the optimum value and at greater intervals for extreme values.

SOLUTION "A" TREATMENT TIME AND BATH TEMPERATURE

The effect of treatment time in Solution A reducing the sheet-to-sheet surface resistance is clearly indicated in Figs. 1 to 9. Figs. 1 and 2, 18 s.w.g. D.T.D. 390 and 20 s.w.g. D.T.D. 610B, respectively, are characterised by the U-form of the curve. A similar tendency is observed in the curves for 20 s.w.g. D.T.D. 687. In all other cases, i.e. in the thicker gauges of both alloys, once the lowest resistance is attained there is no substantial increase in resistance as the treatment time is prolonged within practical limits.

The most critical material for cleaning is the 20 s.w.g. D.T.D. 610B, the period of lowest resistance extending over a two-minute period only. The lowest resistance attained is also higher than that for all other gauges of both alloys.

Resistance/time curves have also been determined for 20 s.w.g. D.T.D. 610B and D.T.D. 687 for a bath temperature of 27 deg. C. (Fig. 4). This probably represents the highest bath temperature to be expected under summer conditions in the laboratory, and is 7 deg. C. above the average bath temperature for the tests recorded in the other graphs. Increase of temperature is associated with increased bath activity, and it was anticipated that the greatest effect would be apparent in the 20 s.w.g. material. Values of resistance determined for the other gauges at the bath temperature of 27 deg. C. are given in Table I.

The effect on 20 s.w.g. D.T.D. 610B is very marked and it is not possible to control the process satisfactorily to ensure attainment of the lowest value. The effect of increased bath temperature with 20 s.w.g. D.T.D. 687 is only to reduce the time at which the lowest resistance is attained. These points are clearly illustrated in Fig. 4.

Table I. Mean Values of Sheet-to-Sheet Resistance with Solution A, at different Bath Temperatures*

Material	Sheet-to-Sheet Resistance (16 s.w.g.)		Sheet-to-Sheet Resistance (14 s.w.g.)	
	27° C	20° C	27° C	20° C
D.T.D. 610B	7	3·9	5	5·1
D.T.D. 687	6	4·0	6	3·7

* Treatment time, eighteen minutes.

VARIANCE ANALYSIS AND TESTS OF SIGNIFICANCE

(a) Variance Analysis

The curves given in Figs. 1 to 9 show the variation in mean resistance with time-of-treatment. It is possible to derive from these curves times of treatment to give lowest resistance,

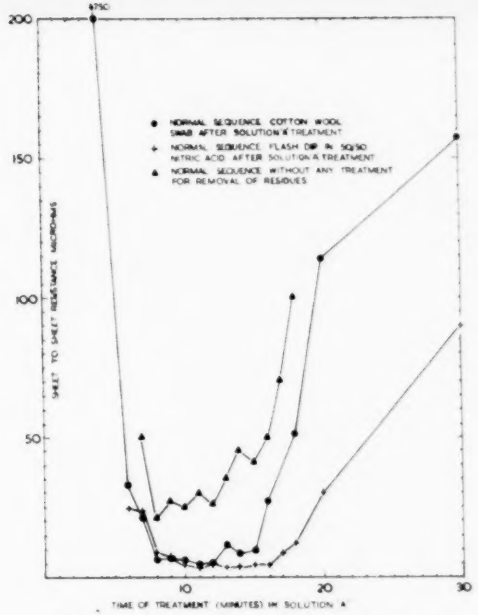
SHEET TO SHEET RESISTANCE MICROHMS
TIME OF TREATMENT (MINUTES) IN SOLUTION 'A'
NORMAL SEQUENCE COTTON WOOL SWAB AFTER SOLUTION 'A' TREATMENT
NORMAL SEQUENCE FLASH DIP IN 50/50 NITRIC ACID AFTER SOLUTION 'A' TREATMENT
NORMAL SEQUENCE WITHOUT ANY TREATMENT FOR REMOVAL OF RESIDUES

Fig. 1. Surface treatment of 18 s.w.g. D.T.D. 390.

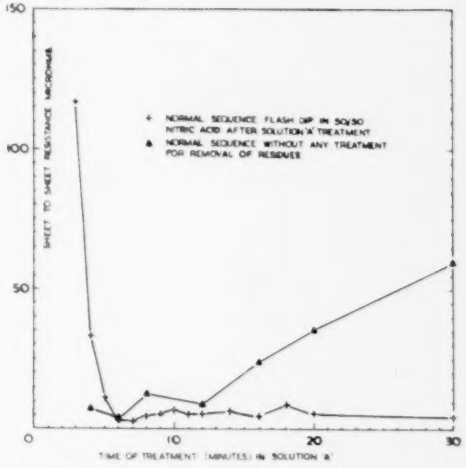
SHEET TO SHEET RESISTANCE MICROHMS
TIME OF TREATMENT (MINUTES) IN SOLUTION 'A'
NORMAL SEQUENCE FLASH DIP IN 50/50 NITRIC ACID AFTER SOLUTION 'A' TREATMENT
NORMAL SEQUENCE WITHOUT ANY TREATMENT FOR REMOVAL OF RESIDUES

Fig. 3. Surface treatment of 20 s.w.g. D.T.D. 687.

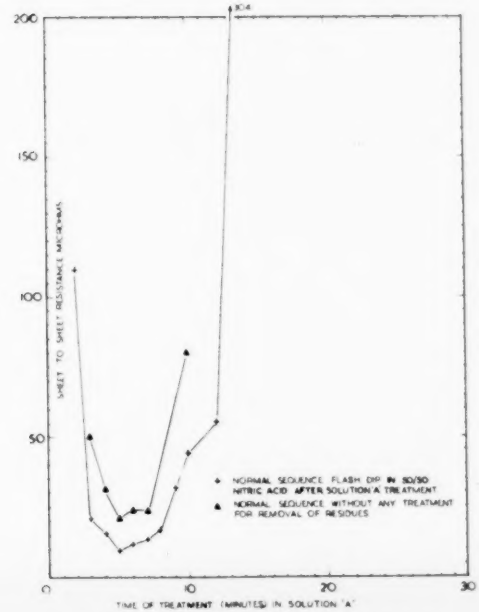
SHEET TO SHEET RESISTANCE MICROHMS
TIME OF TREATMENT (MINUTES) IN SOLUTION 'A'
NORMAL SEQUENCE FLASH DIP IN 50/50 NITRIC ACID AFTER SOLUTION 'A' TREATMENT
NORMAL SEQUENCE WITHOUT ANY TREATMENT FOR REMOVAL OF RESIDUES

Fig. 2. Surface treatment of 20 s.w.g. D.T.D. 610B.

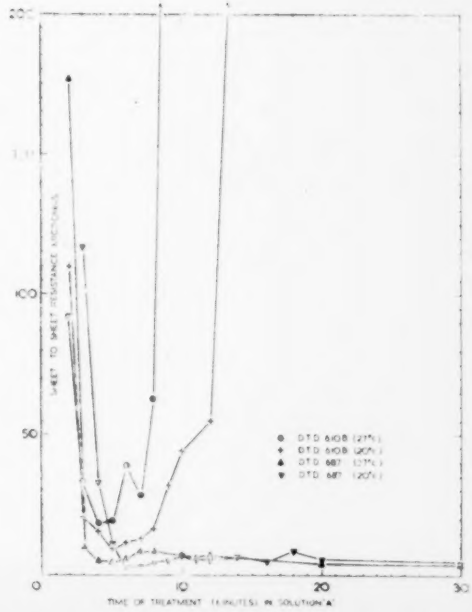
SHEET TO SHEET RESISTANCE MICROHMS
TIME OF TREATMENT (MINUTES) IN SOLUTION 'A'
D.T.D. 610B (21°C)
D.T.D. 610B (20°C)
D.T.D. 687 (21°C)
D.T.D. 687 (20°C)

Fig. 4. Effect of Solution A bath temperature for 20 s.w.g. D.T.D. 610B and D.T.D. 687.

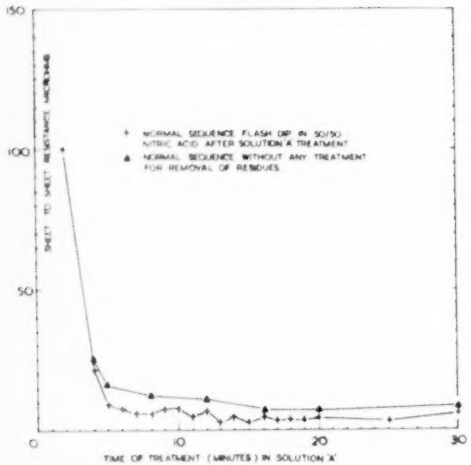

Fig. 5. Surface treatment of 16 s.w.g. D.T.D. 610B.

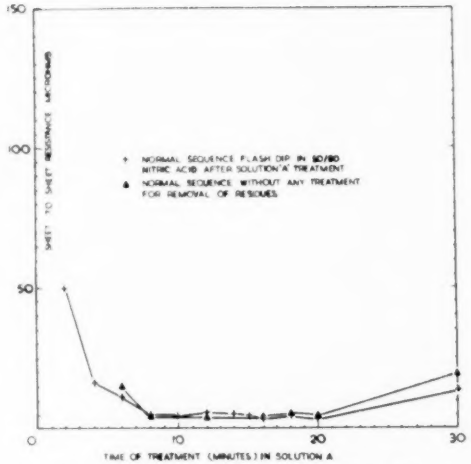

Fig. 7. Surface treatment of 14 s.w.g. D.T.D. 610B.

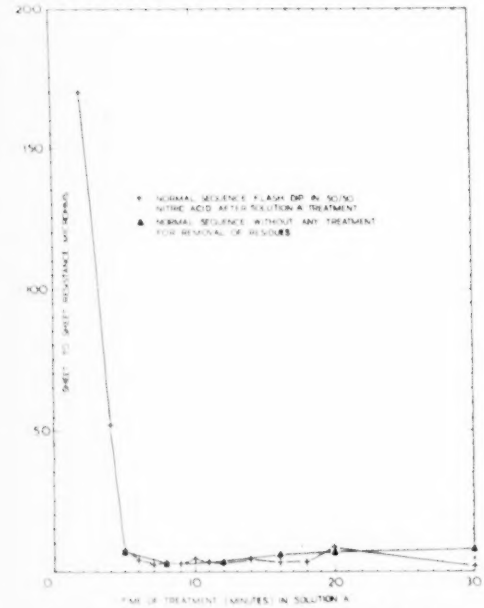

Fig. 6. Surface treatment of 16 s.w.g. D.T.D. 687.

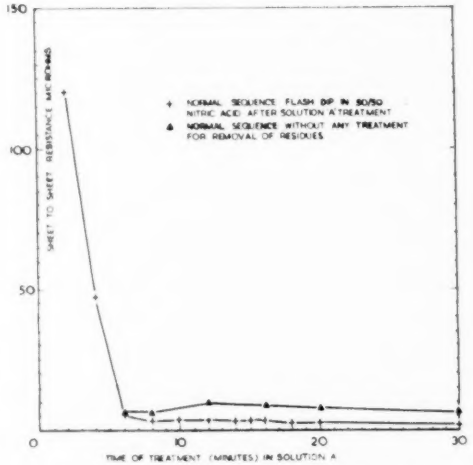

Fig. 8. Surface treatment of 14 s.w.g. D.T.D. 687.

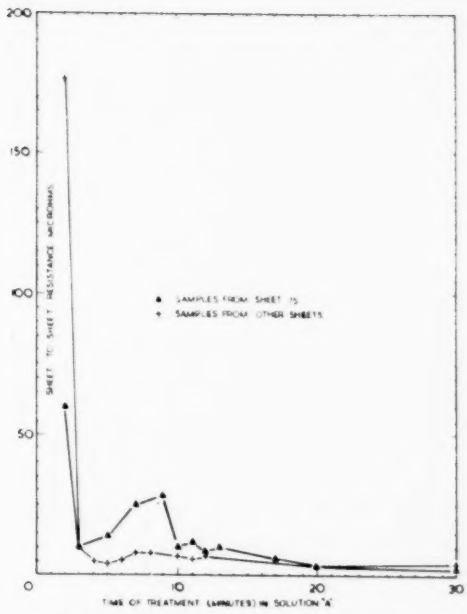

Fig. 9. Surface treatment of 20 s.w.g. D.T.D. 687 (*Solution A bath temperature, 27 deg. C.*)

but values determined in this manner will not take account of the scatter of individual results about the mean.

Further, it is important that any conclusions and particularly those based on human judgment, be checked by the application of tests of significance. The technique adopted in this instance was to estimate a suitable time range of treatment from Figs. 1 to 9. The assumption underlying the existence of a suitable range of treatment time being that the resistance values for a given time do not differ significantly from those for other times within the range, i.e. that the "between" times variance does not differ significantly from the "within" times variance. The between-times variance was compared with the within-times variance for a given range by means of the variance ratio test. The method of calculation is described in full in Appendix II. Satisfactory time ranges determined in this manner are given in Table II.

(b) Tests of Significance

It has also been shown by the technique of "comparison of means" for the "5 per cent. significance level" that there is no significant difference in the mean values of sheet-to-sheet resistance obtained for 16 or 14 s.w.g. D.T.D. 610B and D.T.D. 687. A time of treatment of eighteen minutes is equally satisfactory for all these materials and, for these conditions, it can be concluded that there are no fundamental differences in the bath reaction of 16 and 14 s.w.g. D.T.D. 610B and D.T.D. 687.

The mean resistance values for 20 s.w.g. D.T.D. 610B and D.T.D. 687 are significantly different from the other materials and from themselves, and this is in accord with previous experience of *thin* materials.

The peculiar behaviour of sheet 75 (20 s.w.g. D.T.D. 687) is illustrated in Fig. 9 and it might reasonably be concluded from the graph that a time of twenty to thirty minutes is suitable for sheet 75 and about seven minutes for the other sheets. However, it has been shown by the method indicated above that the best time of treatment for both groups of materials is from twenty to thirty minutes. There can be no doubt, however, in spite of this conclusion, that (for shorter

Table II.—Statistical Analysis of Experimental Data

Thickness (s.w.g.)	Specification D.T.D.	Time * Range (mins.)	No. of Tests	Mean Values Sheet-to-Sheet Resistance (microhms)	$\Sigma(x)^2$	$(\Sigma(x)^2/n$	Variance σ^2	Between-times Mean Square	Within-times Mean Square	Variance Ratio	Variance Ratio at 5 per cent. Level	95 per cent.† Confidence Limits for	
												Means (range)	Individual Results (range)
20	610	5-6	24	11·400	3529·25	3116·70	17·9400	13·740	18·120	1·319	249·0	9·6 — 13·2	20·2 — 2·6
	687	20-30	6	5·420	177·75	176·05	0·3400	1·030	0·170	6·060	7·7	4·8 — 6·0	3·9 — 6·9
	687 (Sheet 75)	20-30	6	4·170	107·00	104·17	0·7520	0·660	0·540	1·220	7·7	3·4 — 5·0	2·2 — 6·1
16	610	17-19	9	3·890	137·00	136·10	0·1125	0·050	0·130	2·600	19·3	3·6 — 4·2	3·1 — 4·7
	687	6-30	81	4·025	1546·00	1312·05	2·9240	2·182	2·5	3·043	1·395	3·6 — 4·4	0·6 — 7·4
14	610	8-20	63	5·100	1806·00	1635·60	2·7500	4·110	2·570	1·600	2·4	4·7 — 5·5	1·8 — 8·4
	687	8-30	66	3·710	989·50	909·40	1·2320	2·240	1·090	2·060	2·3	3·4 — 4·0	1·5 — 5·9

* For these times there is no significant difference between the within-times mean square and the between-times mean square

† 95 per cent. of all values can be expected to lie within these limits

times) the two groups of material do react differently to treatment in Solution A. This may be due to difference arising out of variable core diffusion into the coating, but it has not yet been possible to confirm this suggestion.

The value of mean resistance determined from the experimental results is only an estimate of the true population mean from which the sample was drawn. The value of the data is increased by an estimate of the limits within which the true population mean can be confidently expected to lie. A confidence limit of 95 per cent. means that the mean value has a 95 per cent. chance of lying anywhere between the limits; 95 per cent. confidence limits have been determined for mean and individual values and are given in Table II. The wide spread of the mean values and individual values for 20 s.w.g. D.T.D. 610B should be noted.

EFFECT OF SURFACE RESIDUES ON RESISTANCE

The materials under investigation are coated alloys D.T.D. 390 and D.T.D. 610B, being coated with 99·9 per cent. purity aluminium and D.T.D. 687 with Al-Zn (0·75 to 1·25 per cent.) alloy. It is possible that core diffusion takes place during manufacture, in particular, the diffusion of copper into the cladding. The effect of such diffusion is to produce a "smut" on the surface of the alloy when treated with certain chemical reagents. This smut can be removed either by rubbing down with a cotton wool swab in water or by a nitric acid solution.

There is no obvious visible smut produced on any of the material with Solution A, but a cotton-wool swab soon discolours when used to rub down the thinner gauges of D.T.D. 610B and 687 after treatment.

Hand swabbing of treated 18 s.w.g. D.T.D. 390 had a noticeable effect on the sheet-to-sheet resistance (Fig. 1), and a further improvement was obtained by a flash dip 50/50 nitric acid. This treatment was of value in all other cases, but particularly in the thinner sheets. The effect on the 14 s.w.g. D.T.D. 610B and D.T.D. 687 was less marked, but this was to be expected, owing to reduced core diffusion associated with the thicker gauges. Reference should be made to Appendix III for further discussion on this matter.

TEMPERATURE AND DURATION OF HOT WASH

It was known that the final wash (hot distilled water) was important in determining the surface resistance. Distilled water has to be used because of the high lime content of the local supply. The final hot wash is used to wash off the normal mains water (which would otherwise leave a high resistance lime residue) and to heat the material so that it would dry quickly after immersion. However, the requirements to obtain a low surface resistance, namely, low temperature, also demand a short immersion time. As the temperature of the bath or the duration of the washing is increased, the surface resistance increases accordingly. Tests were required to determine a satisfactory working compromise. These are summarised in Table III.

Table III. Effect of Hot Distilled Water Wash on Sheet-to-Sheet Surface Resistance of 18 s.w.g. D.T.D. 390.*

Washing Treatment in Distilled Water	Sheet-to-Sheet Resistance (Microhms.)†
Three minutes at 56 deg. C.	21·5
Flash dip at 56 deg. C. (rinse)	11·0
Three minutes at 45 deg. C.	14·0
Flash dip at 45 deg. C. (rinse)	9·0

* Eight minutes in Solution A
† Average of thirty results

CONCLUSIONS

1. There is no significant difference (5 per cent. level) between the mean values of sheet-to-sheet resistance within the recommended time range (Table IV) for 16 or 14 s.w.g. D.T.D. 610B and D.T.D. 687.

2. Mean values for 20 s.w.g. D.T.D. 687 and D.T.D. 610B are significantly different from remainder and from themselves.

3. For all gauge thicknesses a greater latitude in time of treatment is possible for D.T.D. 687.

4. 20 s.w.g. D.T.D. 610B is particularly difficult to clean, and it is not possible to achieve a minimum resistance as low as that for other gauges of D.T.D. 687 and D.T.D. 610B. This behaviour is probably due to excessive diffusion of core constituents into the cladding (Appendix III). Scratch brushing is recommended when a very low resistance is required.

5. The cleaning technique adopted gives very satisfactory results for all gauges except 20 s.w.g. D.T.D. 610B.

6. The use of a flash dip in 50/50 nitric acid after the Solution A bath is particularly advantageous for the removal of surface residues on the thinner gauges.

7. Variations in bath temperatures within the range 17 deg. C. to 27 deg. C. have little effect on the sheet-to-sheet resistance of all gauges except 20 s.w.g. D.T.D. 610B.

8. Final washing should be by rinsing in distilled water at 45 deg. C. Prolonged washing times and temperatures in excess of 50 deg. C. are very undesirable and give rise to a deleterious increase in resistance.

9. Different sheets of the same thickness and same composition from the same cast (20 s.w.g. D.T.D. 687) can react differently to the Solution A bath (Fig. 9), but times of treatment from twenty to thirty minutes give equally satisfactory results.

Table IV. Solution A Treatment Time to Give Lowest Sheet-to-Sheet Resistance
(Bath Temperature, 20 deg C. ± 3 deg. C.)

Thickness (s.w.g.)	Specification D.T.D.	Time Range* (mins.)	Recommended Time† (mins.)	Mean‡ Resistance Over Time Range (microhms)	Mean‡ Resistance by Scratch Brushing (microhms)
20	610	5-6	5	11·4	4·6
20	687	20-30	20	5·4	3·8
16	610	17-19	18	3·9	2·1
16	687	6-30	18	4·0	3·1
14	610	8-20	18	5·1	2·4
14	687	8-30	18	3·7	3·3

* Satisfactory time range for lowest resistance has been derived from variance analysis of results.
† Recommended times are within time range quoted but have been fixed by practical considerations.
‡ Resistances quoted are measured from sheet to sheet.

Recommended Cleaning Sequence

10. A cleaning sequence has been established to give the optimum or lowest values of surface resistance. For the range of treatment time quoted in Tables III and IV the scatter in individual results for a given time do not differ significantly from that between the times in the range, i.e. the "between-times" mean square does not differ significantly from the "within-times" mean square.

Degreasing

(i) Suspension in trichlorethylene vapour degreasing unit.
(ii) Dirt film and identification marks, left after Treatment 1, removed by rubbing with clean, dry mutton cloth.
(iii) Treatment in Zonax degreasing bath at 90 deg. C. for ten minutes (6 oz. Zonax per gallon).
(iv) Cold wash in running water. The material should show a "no-water break" surface, indicating freedom from grease.

Removal of Oxide Film

(v) Treatment in Solution A at room temperature for prescribed time. (Times giving lowest values of resistance are given in Table IV.)
(vi) Rinse in cold water.
(vii) Flash dip in 50/50 nitric acid solution to remove surface residues.

Washing

(viii) Cold wash in running water for two minutes.
(ix) Rinse in distilled water at 45 deg. C.
(x) Specimens freely suspended in warm air until all water has drained away.
(xi) Resistance measurements taken within thirty minutes of completion of cleaning.

The minimum value obtained for 20 s.w.g. D.T.D. 610B is much higher than that for any other material and accordingly scratch brushing is recommended when a much lower mean resistance is required. The peculiar behaviour of this material is discussed further in Appendix III.

ACKNOWLEDGMENTS

The author is grateful to Messrs. G. Phipps and M. D. Hannah, Engineering Assistants of the B.W.R.A. Research Station, Abington, for their valuable help in carrying out the work described in this report, and to Mr. J. E. Roberts for his active co-operation in the later stages of the work and of the statistical analysis of results.

APPENDIX I

The Measurement of Surface Resistance

The method used involves the passing of a known current (20 amps.) through two strips of material overlapped for approximately three-quarters of their length and held between ½-in. tip diameter electrodes at a constant load of 900 lb. obtained by means of an air-operated press. The potential difference across the two specimens is measured by a sensitive millivolt meter of 3mV full-scale deflection with 150 sub-divisions. Voltage connections are made by crocodile clips, one being attached to each sheet. The determination of sheet to sheet resistance is preferable to electrode to sheet resistance when a comparison between the efficiency of different cleaning techniques is required. In this way contamination of the electrode does not affect the results.

The sheet-to-sheet resistance value determined includes that of the body resistance of two half sheets of material.

Safety measures are incorporated in the equipment to avoid passing current before the correct electrode load has been obtained. A pressure switch is arranged to operate a solenoid which controls the flow of current. The voltage clips are then attached to the strips and a meter deflection obtained by depressing a switch. The meter is allowed to stabilise before taking a reading. With a current of 20 amps. the meter reads directly in microhms, i.e. each division equals one microhm.

The method is suitable *only for comparative purposes*, i.e. determining the suitability of different cleaning techniques.

APPENDIX II

The Method of Variance Analysis and Significance Tests

The detailed analysis was only applied to those tests using the full normal cleaning sequence with flash dip in 50/50 nitric acid, the main variable in these tests being time of treatment in Solution A. Individual values of sheet to sheet resistance for 20, 16 and 14 s.w.g. D.T.D. 610B and D.T.D. 687 are given in Tables 6 to 9 inclusive.

The method of calculation is given in full for 16 s.w.g. D.T.D. 687.

The hypothesis to be tested is that there is no significant difference in the time of treatment within the range six to thirty minutes, i.e. that the within times mean square—a measure of the experimental error, does not differ significantly from the between times mean square—a measure of the effect of treatment time. The steps in the calculations are as follows:

1. Square all the individual values in the range six to thirty minutes (Table VIII) for D.T.D. 687 and sum the squares:
   Answer: 1546·0.
2. Square each row total, divide by the number of individuals in that row and sum these terms:
   Answer: 1336·05.
3. Square the grand total and divide by the number of individuals:
   Answer: $\frac{326^2}{81} = 1312{\cdot}05$.

The analysis of variance proceeds as below in Table V.

Table V

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares
Between-times	(2)-(3) = 24·00	11	2·182
Within-times	(1)-(2) = 209·95	69	3·043
Total	(1)-(3) = 233·95	80	—

The variance ratio is then given by 3·043/2·182 = 1·395 for degrees of freedom $N_1 = 69$ and $N_2 = 11$.

For the 5 per cent. level of significance one can expect a ratio as high as 2·4 (approximately) so that in this case there is no evidence that alteration in time of treatment has any effect on the sheet to sheet resistance.

Confidence limits for a single mean are calculated as follows:

The limits $\pm$ L on either side of the sample mean are given by

$$\pm L = \pm t\left(\frac{\sigma}{\sqrt{n}}\right)$$

where σ is the standard deviation of the population and n is the number of individuals in the sample. Students "t" is determined according to the appropriate significance level and number of degrees of freedom. In this case for the 5 per cent. level and 80 deg. of freedom, "t" equals 1·99 (approximately).

$$\sigma^2 = \frac{\Sigma x^2 - (\Sigma x)^2/n}{n-1} = \frac{1546 - 1312{\cdot}05}{80} = 2{\cdot}924$$

$$\sigma = 1{\cdot}71$$

$$\pm t\frac{\sigma}{\sqrt{n-1}} = 1{\cdot}99\frac{1{\cdot}71}{\sqrt{81}} = \pm 0{\cdot}378.$$

The mean value is 4·025 so that the 95 per cent. confidence limits are 3·6 and 4·4.

For individuals the limits on either side of the mean are given by $\pm t\sigma$.

Table VI. 20 s.w.g. Material. Bath Temperature 20 deg. C. Sheet-to-Sheet Resistance, Microhms

Time of Treatment (mins.)	D.T.D. 687	D.T.D. 610B
2	Off scale. 150	80, 81, 114
3	150, 50, 150	17, 19, 20, 20·5, 30, 22
4	17, 18·5, 15, 48, 48, 52·5	34, 22·5, 20, 12, 16·5, 9·5, 10·5, 12, 11·5
5	11·5, 10·5, 11·5	8·5, 9, 10, 9·5, 12, 11·5
6	3, 3·5, 2·5, 4, 5, 5, 2·5, 2·5, 3	15, 17, 16, 14, 14·5, 16·5, 9, 8, 9·5, 11, 9, 9, 11·5, 10, 11·5, 13, 15, 13·5
7	5, 4, 4, 2, 2, 2, 2·5, 3, 3·5	16, 14, 21, 17, 19·5, 22, 7, 8, 7, 9·5, 15·5, 10·5
8	3·5, 4, 3, 3, 2·5, 2, 6·5, 8·5, 10, 5, 4, 4	13, 11, 18, 17, 21, 21
9	4, 5, 4·5, 7, 6·5, 5·5	17, 18·5, 25, 71, 33, 25
10	6, 7, 8, 7, 6, 9	25, 23·5, 44, 68·5, 38, 65
12	5·5, 5·5, 6, 6, 5, 5, 4·5, 6, 6, 5·5, 6	21, 5, 20·5, 16, 8, 10, 11·5, 96, 104, 85, 114, 104, 72
14	9, 7·5, 8, 6, 5·5, 6	225, 150, 825, 275, 175, 175
16	5, 5, 5·5	150, 150, 113
18	6·5, 11·5, 9·5	400, 425, 700
20	5·5, 6, 6	275, 350, 450
30	4·5, 5, 5·5	700, 125, 900

Table VII. 20 s.w.g. Material. Bath Temperature 27 deg. C. Sheet-to-Sheet Resistance, Microhms

Time of Treatment (mins.)	D.T.D. 687		D.T.D. 610B
	Sheet 75	Other Sheets	
2		Off scale	80, 81, 114
3	7, 9, 13		27·5, 45, 25·5
4		5·5, 4·5, 5	15, 18·5, 20
5	11·5, 18·5, 13	4, 4·5, 5	6·5, 8·5, 10·5, 12, 20, 19, 9·5, 18·5, 19·5, 20·5, 26·5, 25·5
6		5·5, 5·5, 5	57·5, 33, 25
7	13, 22, 12, 7·5, 11, 17·5, 23·5, 41 78	5, 9, 8, 7, 8·5, 11·5	29, 27·5, 28
8		7, 10, 6	80, 73, 47
9	24, 24, 26, 13·5, 31, 48		Off scale
10	7, 12·5, 11	5, 6, 9	77, 78, 135
11	10·5, 11·5, 12·5	2·5, 7·5, 7	13, 64, 54
12	10·5, 8·5, 7·5	7, 8, 5	149, 120. Off scale
13	9, 10, 11		
17	5·5, 6·5, 7·5		
20	4·5, 4, 4, 3·5, 5, 4	3·5, 3·5, 4·5	Off scale
30	3, 3·5, 3·5	3·5, 5, 5	Off scale

Table VIII. 16 s.w.g. Material. Bath Temperature 20 deg. C. Sheet-to-Sheet Resistance, Microhms

Time of Treatment (mins.)	D.T.D.	D.T.D. 610B
4	66, 42, 47	14, 25, 23
5	5·5, 8, 9, 8·5, 7·5, 8	8·5, 9·5, 12, 7, 10, 10
6	4, 4·5, 5, 4, 4·5, 4	8, 8, 10, 7·5, 8·5, 6
7	2·5, 2·5, 3, 4, 4, 4	6·5, 7, 8, 5, 6, 7
8	4, 5, 4, 2·5, 2·5, 3, 4·5, 4, 4·5, 3·5, 3·5, 4	5·5, 7·5, 7·5, 5·5, 5, 5·5, 7·5 6·5, 8, 4·5, 4·5, 4
9	2·5, 3, 3, 3·5, 3, 3	7·5, 7·5, 7, 6, 8·5, 7·5
10	6, 5·5, 5, 3·5, 4, 4	5, 4, 5·5, 8, 12·5, 10·5
11	2·5, 3·5, 3, 5, 4·5, 4·5	5·5, 7, 7·5, 3·5, 4, 4
12	3·5, 3, 4·5, 2, 2·5, 3, 3, 2·5, 2·5, 3·5, 4, 4·5	7, 6, 6, 7·5, 8·5, 8, 6·5, 7·5, 4·5
13		3, 3, 3
14	1·5, 2·5, 3, 7, 7·5, 7, 5, 5, 6, 5·5, 6, 6·5, 2·5, 3, 3·5	3, 3·5, 4·5, 6·5, 8, 7, 6, 7, 6·5, 5·5, 8, 3·5, 4·5, 5·5, 10
15		3·5, 3·5, 3·5
16	3, 4, 3	4·5, 6, 5·5
17		4, 4, 3·5
18	3·5, 4, 4	3·5, 3·5, 4·5
19		4, 4, 4
20	9·5, 7·5, 11·5	5·5, 5, 5
25		3, 2·5, 2·5
30	2·5, 2·5, 2·5	4, 5·5, 7·5

Table IX. 14 s.w.g. Material. Bath Temperature 20 deg. C. Sheet-to-Sheet Resistance, Microhms

Time of Treatment (mins.)	D.T.D. 687	D.T.D. 610B
4	47·5, 58, 36·5	16, 13·5, 18·5
6	4·5, 6, 6	6, 14, 15
8	4, 3·5, 4, 3, 3, 3	5, 4, 3·5, 7, 4·5, 6
10	4, 4·5, 3, 4, 4, 3·5	6·5, 6, 4·5, 4, 5, 6
12	4·5, 4, 2·5, 4·5, 4·5, 3·5, 4·5, 4·5, 5, 4, 3·5, 3·5	5, 4·5, 6, 5·5, 4·5, 5·5, 8·5, 9, 9, 8·5, 6, 6·5
14	4, 3·5, 2·5, 4, 4, 3·5	5·5, 6, 7, 6, 5, 3·5
15	1·5, 2, 2, 2·5, 3, 4, 7, 6·5, 4, 4·5, 4, 5, 5, 7, 4·5	4, 2·5, 3·5, 5·5, 6·5, 4·5, 5·5, 5·5, 5·5, 6·5, 5·5, 5, 4, 4·5, 4
16	4, 4, 3·5, 5, 4, 4	4, 5, 3·5, 3·5, 5, 4
18	3, 4, 3·5, 2·5, 2·5, 2·5	5·5, 4·5, 5·5, 4·5, 5·5, 6
20	3, 2·5, 3·5, 3, 4·5, 3	4, 3, 3, 4·5, 4, 5
30	2·5, 2, 2	10, 10, 22

APPENDIX III

The Effect of Core Diffusion into Cladding

Difficulties associated with the pre-welding surface preparation of thin gauges of some coated light alloys have been attributed to differences in manufacture, i.e. heat treatment giving rise to excessive diffusion of core constituents into the cladding. In aluminium coated alloys of the duralumin type, atoms of copper and magnesium and other elements will migrate from the core into the coating on heat treatment, and it is to be expected that under the same condition the concentration of diffused elements in the cladding on thin gauges will exceed that of the heavier gauges with the relatively thicker cladding. On the assumption that copper is the main diffusing element that produces relatively high surface resistance, coated alloys of relatively low copper in the core should be less troublesome than those of relatively high copper content. For this reason, D.T.D. 610B might be expected to show more core diffusion than D.T.D. 687.

The composition and properties of the materials used to these specifications are given in Table X.

The detection of diffused copper in the cladding by the usual method of microscopic examination of polished and etched sections is difficult, but Keller* recommends the use of specially etched surface sections of sheet.

In this method the natural sheet surface is degreased only and etched exactly five seconds in 5 per cent. sodium hydroxide solution and then etched for exactly sixty seconds in Keller's reagent. The amount of copper diffusion to the surface is indicated by the extent to which the surface microstructure is developed in etching.

This method has been used on samples taken from representative sheets of the various gauge thicknesses and the following conclusions drawn:

1. Marked cellular structure outlining grain boundaries in 20 s.w.g. D.T.D. 687. The development of grain boundaries is taken as an indication of copper diffusion to the surface.
2. Identity of cellular structure in 20 s.w.g. D.T.D. 610B is apparently lost in more extensive diffusion from boundaries to within the grains.
3. No micro-structure of the coating is developed in either 16 or 14 s.w.g. D.T.D. 610B or D.T.D. 687.
4. No difference could be detected between sheet 75 of 20 s.w.g. D.T.D. 687 and other sheets of this gauge.

Further work on this test for detecting copper diffusion seems worth while in view of the above results, and many more tests are necessary to determine whether the results of such an etching test or modified test can be correlated with behaviour during cleaning.

* "Physical Metallurgy of Alluminium Alloys," *Amer. Soc. for Metals*, 1949, pages 115-117.

Table X. Properties and Composition of D.T.D. 610B * and D.T.D. 687 †

0·1 per cent. Proof Stress (tons per sq. in.)	U.T.S. (tons per sq. in.)	Elongation (per cent. on 2 in.)	Fe	Cu	Si	Mn	Mg	Ti	Cr	Zn
(D.T.D. 687, 20 s.w.g.)										
29·8	34·9	12								
(D.T.D. 687, 16 s.w.g.)										
30·3	35·5	12	0·35	1·39	0·17	0·28	2·48	0·04	0·12	5·63
(D.T.D. 687, 14 s.w.g.)										
30·7	34·9	12								
(D.T.D. 610B, 20 s.w.g.)										
16·3	27·8	21								
(D.T.D. 610B, 16 s.w.g.)										
15·9	27·3	21	0·35	4·39	0·73	0·79	0·54			
16·6	28·3	24								
(D.T.D. 610B, 14 s.w.g.)										
15·6	26·6	21								

* Coating not less than 98·7% Al.

† Coated with Al. – 1% Zn.

Addition to our Technique and Memoranda Series

NON-DESTRUCTIVE METHODS FOR THE EXAMINATION OF WELDS

T.29 *The Memorandum outlines the non-destructive methods available for the examination of welds and welded constructions. It has been prepared as an introduction to the subject in order to provide some guidance for engineers and inspectors who may be unfamiliar with the advantages and the limitations of the various methods. Emphasis has been given mainly, therefore, to the scope of application of each method in the field of welding fabrication and only a brief account is included of the different examination techniques and the apparatus required.*

The list set out below indicates the various sections of the Memorandum:

INTRODUCTION

SEMI-DESTRUCTIVE METHODS OF TESTING WELDS

Test Plates attached to Workpiece.
Weld Probing.

RADIOGRAPHIC EXAMINATION METHODS

The X-ray Method of Weld Examination.
The Gamma-Ray Method of Weld Examination.

MAGNETIC METHODS OF WELD EXAMINATION

PENETRANT METHODS OF WELD EXAMINATION

ELECTRICAL METHODS OF WELD EXAMINATION

Induction Method.
Resistance Method.
Eddy Current Method.

CHEMICAL METHODS OF WELD EXAMINATION

Chemical Composition.
Leak Testing.

ACOUSTICAL METHODS OF WELD EXAMINATION

Sonic Methods.
Ultrasonic Methods.

PROOF TEST OR "OVERLOAD" TEST

An appendix to the document indicates the suitability of the various methods in relation to typical joint forms for various welding processes and a further appendix outlines the defects that can normally be found under the best conditions of testing.

Price 5s. post free.

Orders for copies of the above report should be addressed to the Publications Department, B.W.R.A., 29, Park Crescent, London, W.1.

A complete list of publications is available on request.

Printed in England by Lawrence Press Ltd., Henry Road, New Barnet, Herts